RADAR AND SYNOPTIC ANALYSIS OF A TORNADO SITUATION

MORRIS TEPPER

U. S. Weather Bureau, Washington, D. C.

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ABSTRACT

The radar and synoptic analysis of the tornado situation of November 14, 1949, at Pierson, Fla., yields conclusions which are compatible with the author's hypothesis that the interaction zone of two intersecting pressure jump lines is a preferred region for tornado formation. Relevant to the case discussed, another mechanism for producing a pressure jump line is suggested—the "backward" moving pressure jump line.

INTRODUCTION

The pressure jump line, reflected as a sharp discontinuity on a barograph trace, has formed the basis of two earlier papers by this author. In one paper [1], it was proposed that a pressure jump line can be produced by the action of a cold front accelerating into a warm sector which contains a temperature inversion. This type of pressure jump line is related to the prefrontal squall line. In the second paper [2], it was proposed that a pressure jump line can be produced by a strong trade-wind flow coming around the southern edge of the Bermuda High and disturbed by the land mass as this flow traverses the Gulf States. A temperature inversion was required here too. In this paper, a third mechanism for the production of a pressure jump line will be proposed. All of these mechanisms follow from the analogy of pressure jumps in the atmosphere to hydraulic jumps in water and shock waves in the air as developed by Freeman [3].

In each of the two papers by this author mentioned above, it was suggested by analogy to the intersection of two unequal shock waves in gas dynamics that the intersection of two unequal pressure jump lines in the atmosphere would produce a zone of wind shear favorable for tornado formation. In [2], two cases of tornado situations verifying this hypothesis were presented.

In this paper another tornado situation will be presented and it will be shown that all available synoptic data are compatible with the above hypothesis. In addition, radar pictures taken during the period preceding and following the tornado will be presented. The precipitation echoes indicated by these radar pictures will also suggest the possibility that we are dealing with intersecting pressure jump lines. However, it should be kept in mind that these echoes are merely pictures of the portion of the precipitation area "seen" by the radar set and do not represent the pressure jump lines themselves. As suggested in [1], the precipitation pattern results from the forced lifting produced by the pressure jump line and consequently would *normally* lag the pressure jump line in both time and space.

RADAR OBSERVATIONS OF THE STORM OF NOVEMBER 14, 1949

On November 14, 1949, there developed a situation wherein a feature of the radar precipitation echo was found to be directly related to a tornado. Fortunately, continuous radar pictures were made of the storm as it moved across northern Florida. These pictures were brought to the attention of the U. S. Weather Bureau, and prints of them are reproduced in figure 1 with the kind permission of the Electronic Research Laboratory at the University of Florida.[1] On these prints are delineated the precipitation echoes picked up by the radar beam and indicated on the scope. The orientation of the echoes is with respect to north to the top, east to the right, etc. The circular rings represent distances of 20, 40, 60,... miles from the radar set.

The pictures indicate a progressive movement eastward of a long band of precipitation. Furthermore, this long radar echo appears to develop a well defined bend. At 1415 EST this bend is about 40 miles southeast of Gainesville, Fla., while at 1520 EST, the bend, which is now very pronounced, is located 60 miles east-southeast of Gainesville. It is of interest to note that the portion of the echo that is oriented NW-SE appears to extend beyond the

[1] Among the many institutions and agencies engaged in adapting radar techniques to meteorological needs is the Electronic Research Laboratory, Engineering and Industrial Experiment Station, University of Florida at Gainesville. For example, in Bulletin No. 29 [4], issued by this laboratory, there is given a completely documented discussion of the radar observation of the Florida Hurricane of August 26–27, 1949. Of singular significance to the purposes of this paper is the discussion of the authors, Latour and Bunting, relative to tornado occurrence. They observed that occasionally there developed on the spiral bands surrounding the eye of a hurricane, "wave" disturbances which were apparent for only a short time and which moved along the bands toward the center of the storm. Latour and Bunting propose that these "waves" may develop into tornadoes such as have been observed to occur within the radius of a hurricane. Such "waves," they postulate, are caused by the intrusion of colder and drier inland air into the warmer and moister air of the storm. The author of this paper concurs with the proposal that the "waves" on the hurricane bands may be related to tornado development but for a reason other than that proposed above. It has been suggested (orally by Dr. Harry Wexler, Chief, Scientific Services Division, U. S. Weather Bureau) to the author that hurricane bands might be manifestations of pressure jump lines. As such, "waves" on these bands might be the radar pictures of the cloud pattern produced by the intersection of pressure jump lines. It would follow then that "waves" on hurricane bands are but a special case of the manifestation of the intersection of pressure jump lines.

The case presented in this paper is *not* that of a tornado produced in the circulation of a hurricane, but rather represents the more general case of a wave on a radar precipitation echo and its direct relation to tornado occurrence.

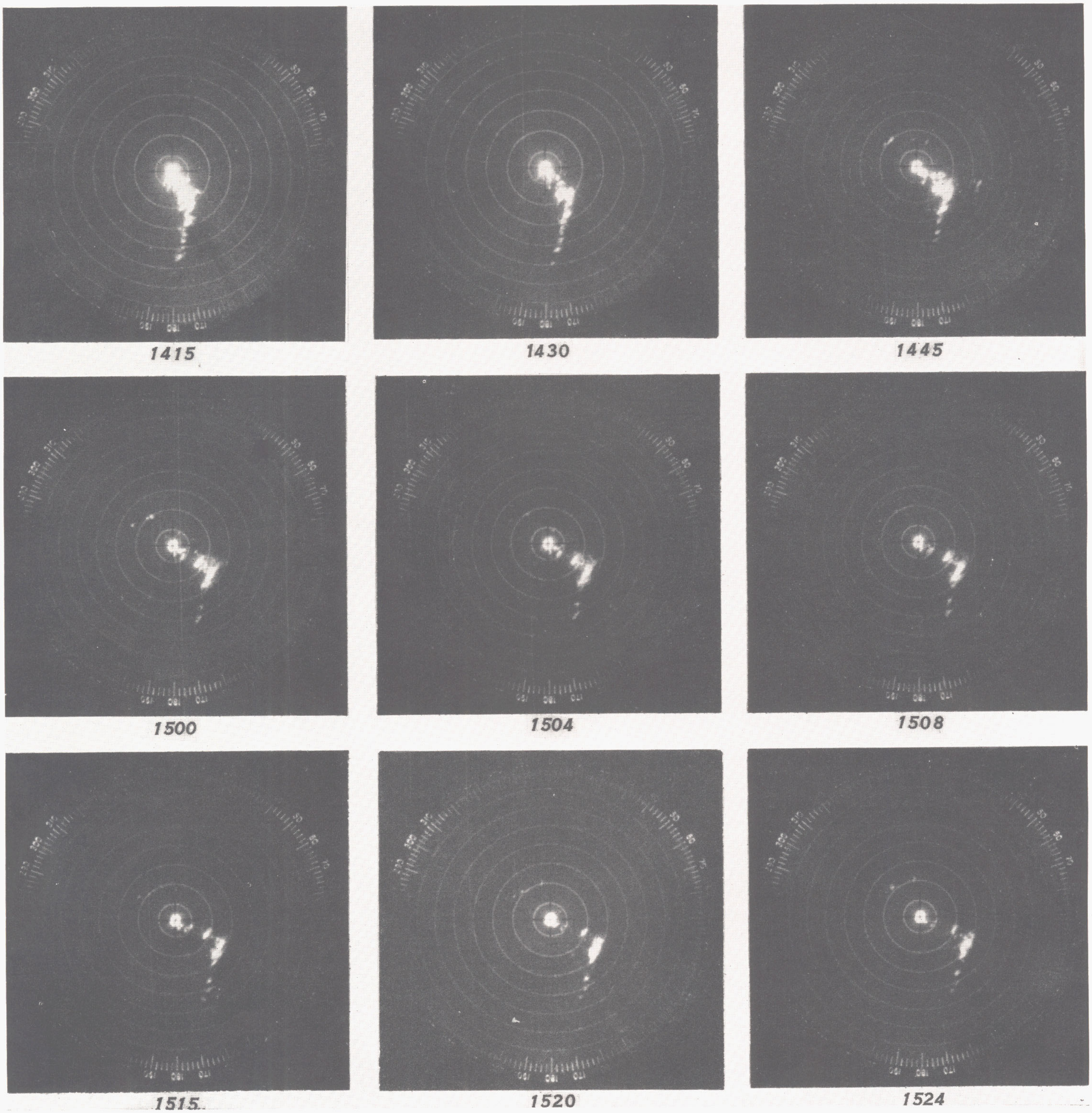

FIGURE 1.—Prints of radar pictures of the November 14, 1949, storm, taken at the Electronics Research Laboratory, Engineering and Industrial Experiment Station, University of Florida at Gainesville (reproduced here with permission of the Laboratory).

bend at 1445 EST. This might suggest an intersection of two systems in the shape of an X, but with that portion of each system lying to the east of the point of intersection being of insufficient intensity to produce precipitation echoes on the radar scope.

A tornado was reported to have struck Pierson, Fla. at 1520 EST. Pierson is located 58 miles from Gainesville and at an angle of 119°. This is in *perfect agreement* with the position of the sharp bend on the precipitation echo picture of 1520 EST.

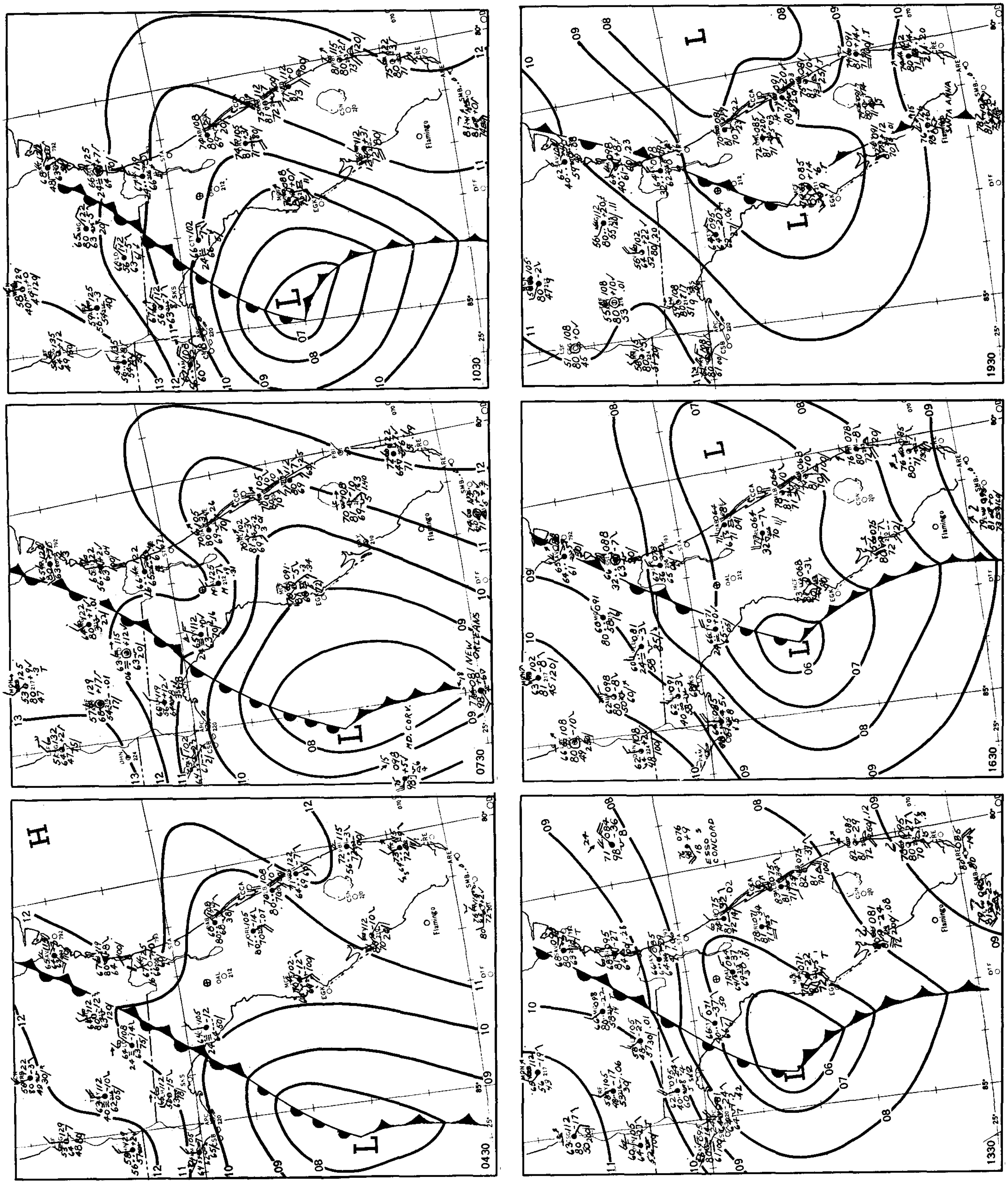

FIGURE 2.—Portion of the surface synoptic map for 3-hourly periods from 0430 to 1930 EST, November 14, 1949. ⊕ indicates the location of Gainesville.

SYNOPTIC SITUATION

SURFACE DATA

Figure 2 shows portions of the surface synoptic maps for the southeastern corner of the United States for three-hourly periods from 0430 to 1930 EST, November 14, 1949. There are three very interesting features to be noted on these maps:

1. The front running northeastward from the wave in the Gulf of Mexico remained practically stationary throughout the period.
2. The cold front associated with this wave moved from its position in the Gulf at 0430 EST to a position roughly parallel to the western Florida coastline by 1930 EST. Unfortunately the absence of adequate data in the Gulf makes it impossible to place accurately the progressive positions of this cold front. It is not unreasonable, however, to assume that at some time after 0430 EST this front could have accelerated.
3. A trough oriented roughly NE-SW through central Florida began developing by 0730 EST, reached its maximum intensity at 1330 EST and then moved off the eastern coast of Florida as a low pressure system. It is significant for our purposes that this elongated trough produced easterlies in the northern portion of the State. The wind record at Jacksonville, Fla. given in table 1, indicates this development of easterlies after 0430 EST on the 14th.

TABLE 1.—*Surface winds at Jacksonville, Fla., November 14, 1949**

Time	Direction	Speed	Time	Direction	Speed	Time	Direction	Speed
EST		*m. p. h.*	*EST*		*m. p. h.*	*EST*		*m. p. h.*
0030	S	6	0830	E	4	1630	NE	8
0130	S	4	0930	N	6	1730	NE	10
0230	S	3	1030	E	5	1830	NE	7
0330	S	3	1130	E	6	1930	N	6
0430	S	3	1230	E	6	2030	NE	8
0530	E	4	1330	E	7	2130	NE	5
0630	E	4	1430	NE	8	2230	N	7
0730	E	3	1530	NE	7	2330	N	5

*These data were read directly from the Triple Register Recorder Sheets and as such might be considered more reliable than those wind data on the surface synoptic maps with which they may differ, since the latter are subject to errors in coding, transmission, decoding, and plotting.

Since the instrument recording these data will record only one of eight directions of the compass, it is admittedly very difficult to substantiate any claims about true wind shifts. However, in this case it appears that we are dealing with four distinct wind regimes; southerly flow until about 0430 EST, followed by easterly flow to 1330 EST, then northeasterly to 1830 EST, and finally northerly flow. The change from the first regime to the second corresponds to the development of the elongated trough in central Florida. The last change in wind regime coincides with the passage of the cold front as indicated on the 1930 EST map. The change to northeasterlies between 1330 and 1430 EST (the exact time was read as 1412 EST) corresponds to the time when the northward extension of the leading edge of the lower half of the precipitation echo would have passed Jacksonville (fig. 3). This relationship will be discussed further in a subsequent paragraph.

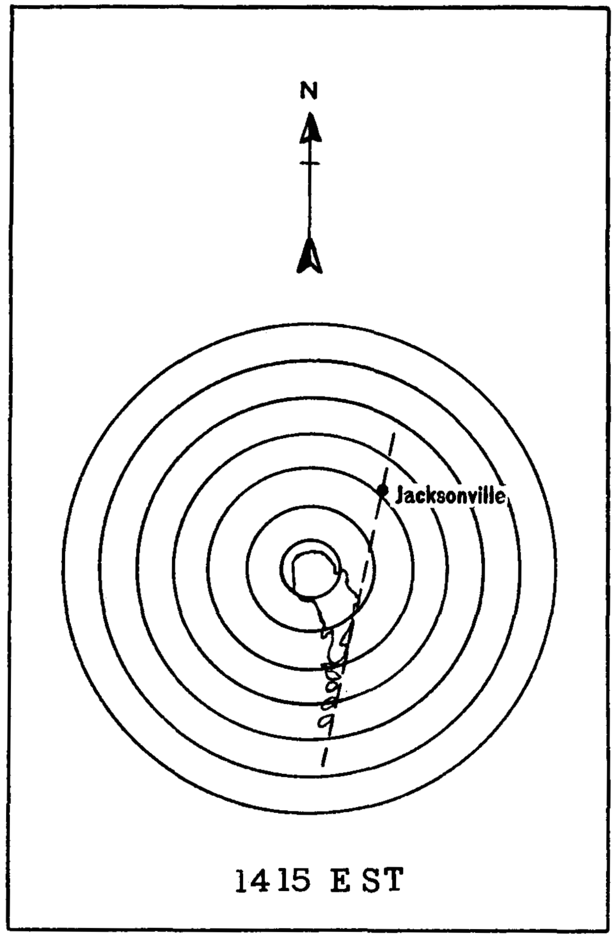

FIGURE 3.—The radar echo at 1415 EST in relation to Jacksonville.

UPPER AIR DATA

The upper air soundings at Miami and Tampa, figures 4a–b, for the morning of the 14th, each indicate a temperature inversion separating moist surface air from *relatively* drier air above. At Miami this inversion was recorded at 760–780 mb., and at Tampa the inversion is found at a lower level, at about 940–960 mb. The only available pibal at Jacksonville for the period immediately prior to the tornado (table 2) clearly indicates a low level wind shear zone corresponding to the zone of transition between the moist and drier layers. Furthermore, the type of weather reported on the surface synoptic maps for northern Florida is representative of that to be expected under stable lapse rate conditions aloft. Therefore, since all available upper air data indicate the presence of an inversion, and in the absence of any evidence to the contrary, it is reasonable to assume that the inversion extended over the entire region.

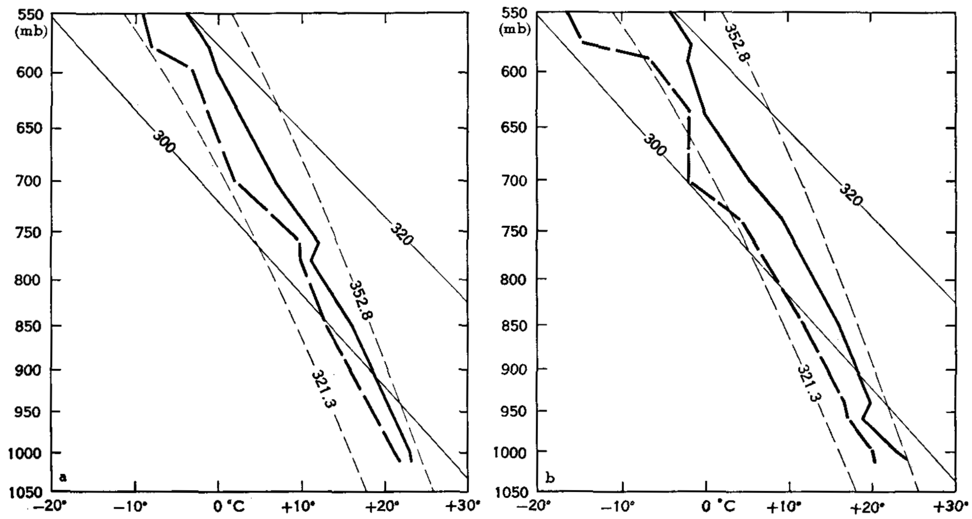

FIGURE 4.—Upper air soundings at (a) Miami. 1500 GMT and (b) Tampa, 1500 GMT, November 14, 1949. The heavy solid line is the temperature curve while the heavy dashed line is that of the dew point. The thin solid and dashed curves are adiabats and pseudo-adiabats, respectively.

TABLE 2.—*Jacksonville pibal 0300 GMT, November 14, 1949 (Wind direction (dd) to 16 points of the compass; speed (ff) in m. p. s.)*

	dd	ff
Surface	6	2
500 m.	8	5
1,000	14	1
1,500	13	4
2,000	11	11
2,500	11	13

RECAPITULATION OF SIGNIFICANT SYNOPTIC FEATURES

The data appear to indicate that we are dealing with the following set of conditions:

1. There is a stationary front in northern Florida oriented generally NE-SW with easterly flow directed into the front.
2. Further south there is a cold front oriented generally NW-SE which we have assumed moved quite rapidly during the morning hours of the 14th of November.
3. Throughout the northern portion of Florida there is a low level inversion.

INTERPRETATION OF THE DATA ACCORDING TO THE TORNADO HYPOTHESIS

To explain the appearance of the precipitation echoes in figure 1 and the occurrence of a tornado at the bend of the echoes we shall utilize the synoptic data described above as well as the tornado hypothesis proposed by the author [1, 2]. This hypothesis states that a preferred zone for tornado formation will result in the interaction zone of two intersecting pressure jump lines. The author has already described how a cold front, moving rapidly into a warm sector could produce a pressure jump line [1]. In our case this pressure jump line would be oriented generally NW-SE (i. e., roughly parallel to the cold front) and could have produced the upper half of the precipitation echoes. The second pressure jump line, oriented NE-SW, and associated with the lower half of the precipitation echoes could be induced by the action of the easterly current against the stationary front in northern Florida. The mechanics of the genesis of such a pressure jump line follows.

With a temperature inversion capping extensive vertical motion, air flow into the stationary front will produce an elevation of the inversion surface, which will progress as a gravitational wave away from the front (i. e., in a direction opposite to that of the flow below the inversion) as indicated in figure 5a. This picture is analogous to the flow of water in an open channel in which an obstruction has been placed (fig. 5b). In this case, a hydraulic jump will be formed and move "backward"; i. e., in a direction opposite to the flow.

Finally, the wind shift at Jacksonville at 1412 EST can now be explained as having been produced by the passage of this second pressure jump line which, in passing, imposed a northerly component on the existing easterly current.

VERIFICATION BY MEANS OF MICROBAROGRAPH DATA

An attempt was made to draw isochrone maps of pressure jump lines as reflected on the barograms, for the purpose of testing directly whether intersections of pressure jump lines were evident. The microbarograms for the 14th were reviewed for indications of pressure jumps. Unfortunately, at only about six stations did discontinuities stand out clearly enough to be considered

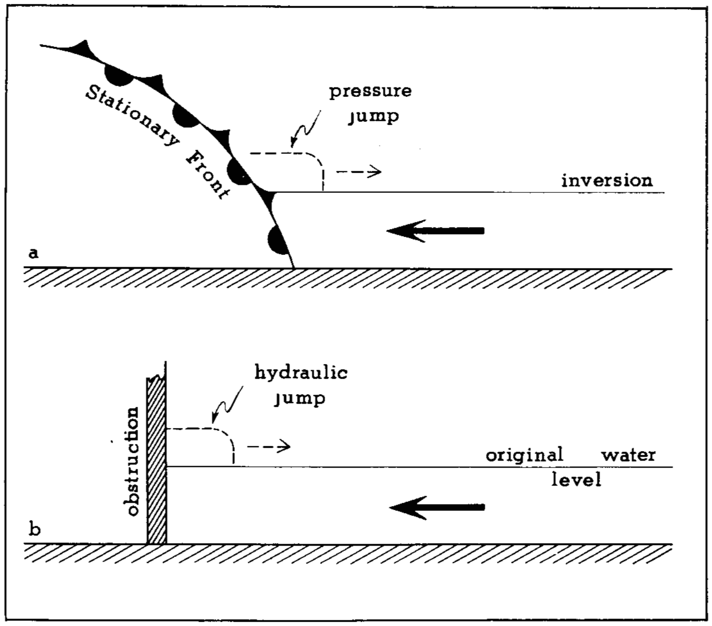

FIGURE 5.—The formation of a "backward" moving (a) pressure jump and (b) hydraulic jump.

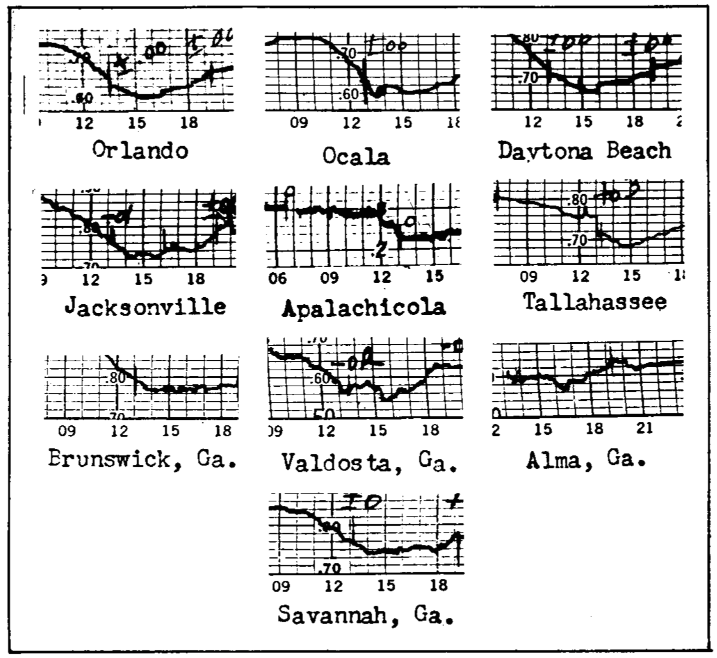

FIGURE 6.—Sections of the microbarograms used in picking off pressure jumps.

possible pressure jumps (fig. 6). Nevertheless, verification was attempted and all irregularities of the barogram for the period 1200–1800 EST that could be made to fall into a pattern of intersecting isochrones were considered. In all there were five different attempts at verification by each of five different analysts. Of these attempts, only two verified the hypothesis. The analysts whose analysis verified included the author and another analyst, both of whom had had previous knowledge of the time and place of the tornado occurrence. The author's intersection pattern, given in figure 7, represents a very good verification for both the tornado occurrence (within 20 miles of its corresponding position on the isochrone intersection line) and for the precipitation pattern represented by the radar pictures (fig. 1).

However, in general the results obtained from the attempts at verification by means of the microbarograph data are far from satisfactory since positive results were obtained by only two of the five analysts. Moreover, all of the analysts complained that the selection of pressure "jumps" was very subjective, and it must be concluded that prior knowledge by the two verifying analysts about the location and time of the tornado probably influenced their choice of barometric flucutations to represent pressure jump lines. On the other hand it should be pointed out that only these two analysts had had any previous experience with the interpretation of barograms for pressure jumps.

CONCLUSIONS

The radar pictures of the storm of November 14, 1949 indicate that a bend on the precipitation echoes corresponds in both time and place with the tornado at Pierson,

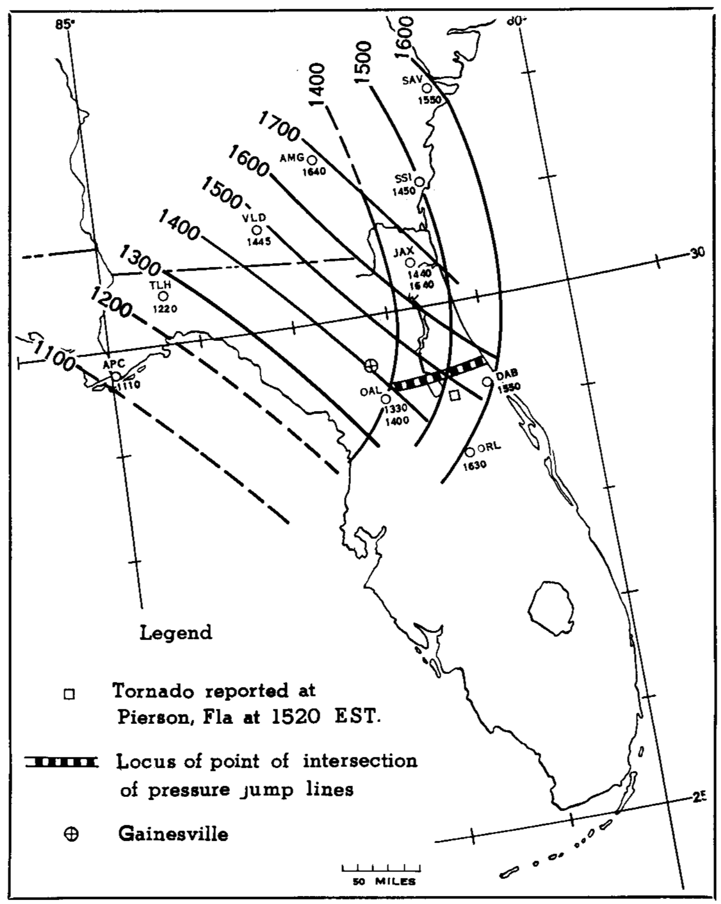

FIGURE 7.—The isochrone pattern for the intersection of two pressure jump lines, November 14, 1949.

Fla. Upon careful investigation, it was found that all available synoptic data were compatible with the conclusion that we are dealing with two intersecting pressure jump lines. These pressure jump lines are considered to have produced the pattern of precipitation echoes indicated on the radar scope. Furthermore, the occurrence of a tornado in the intersection of two pressure jump lines is in accordance with the tornado hypothesis suggested previously by the author. The failure of the microbarograph data to verify the tornado hypothesis more conclusively is attributed to three main factors: (1) the sparsity of reporting stations in the critical area, (2) the nonutilization of high speed microbarographs to separate true pressure jumps from other less sharp pressure rises, and (3) the lack of experience on the part of three of the analysts in interpreting microbarograms for pressure jumps.

ACKNOWLEDGMENTS

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